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Direct Measurement of Denitrification in a *Prosopis* (Mesquite) Dominated Sonoran Desert Ecosystem

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Summary. Denitrification was directly measured using the acetylene inhibition technique in a Sonoran Desert ecosystem dominated by *Prosopis glandulosa*. Soil under *Prosopis* and from the unvegetated area between *Prosopis* was wetted with 50 mm of water and denitrification measured for 48 hours. The mean denitrification rate under *Prosopis* was 11.6 g N ha^{-1} h^{-1} compared to only 0.2 g N ha^{-1} h^{-1} away from *Prosopis*. The denitrification response to wetting was rapid and rates peaked about 24 h after water application. The much higher denitrification under *Prosopis* probably results from high available organic C under *Prosopis,* but other soil chemical and physical changes effected by *Prosopis* may influence denitrification rates. About 0.5 kg N ha^{-1} of *Prosopis* cover may be lost from this ecosystem by denitrification after infrequent major rainfalls.

Introduction

Much of the earth's vegetation grows in arid and semi-arid environments. The extent of the earth's deserts is increasing due to complex interactions involving climatic change, overgrazing and cultivation of marginal lands (United Nations Conference on Desertification 1977). As a consequence, interest in the functioning of desert ecosystems is increasing. Water is considered to be the limiting factor controlling the productivity of desert ecosystems (Fischer and Turner 1978). When adequate water is present, however, soil nutrient factors, e'pecially soil N, may limit desert productivity (Ettershank et al. 1978). Relatively little information is available on N cycling in warm deserts (West and Skujins 1978). Among the processes of desert N cycles, denitrification, the bacterial reduction of soil NO_3^- under anaerobic conditions to gaseous N_2 and/or N_2O, has probably received the least attention (Westerman and Tucker 1978). Low quantities and sporadic distribution of rainfall, coupled with low soil N, are thought to preclude denitrification as a significant factor in desert N cycles.

During an investigation of symbiotic N_2 fixation by *Prosopis glandulosa* var. *torreyena* (Virginia et al. 1981; Rundel et al. 1982) conditions were found which violate the accepted norms for desert systems. In an area of the Sonoran Desert of S. California near the SW shore of the Salton Sea called Harper's Well, groundwater low in total salts ($\psi_{osm} = -0.8$ bar) and N (NO_3-N < 1 mg/l) occurs at 3.5 to 5 m. Here *Prosopis* (mesquite), a woody legume, grows in nearly pure stands. Associated with *Prosopis* at Harper's Well are extraordinarily high levels of soil inorganic N, mostly as NO_3^- (Table 1). In addition to N, organic C concentrations are also much higher under *Prosopis* than the unvegetated soil between *Prosopis* trees. Total soil salinity, however, as well as the sodium adsorption ratio (SAR), are lower under *Prosopis* trees than between trees.

Table 1. Soil chemical properties – *Prosopis glandulosa* stand at Harper's Well

Sample	Depth cm	n	Kjeldahl total N %		Saturation extract NO_3-N µg g^{-1}		KCl extract NH_4-N µg g^{-1}		Total organic C %		Saturation extract ψ_{osm} -bars	
			$\bar{x}$	s.e.	$\bar{x}$	s.e.	$\bar{x}$	s.e.	$\bar{x}$	s.e.	$\bar{x}$	s.e.
Within canopy	0–30	7	0.233	0.006	434	119	6.2	1.4	2.03	0.30	5.85	1.22
	30–60	7	0.057	0.010	178	49	5.6	2.3	0.94	0.25	7.84	1.87
	60–90	5	0.025	0.004	36	18	3.0	0.2	0.44	0.10	6.58	1.92
Edge of canopy	0–30	13	0.081	0.020	263	53	4.8	0.5	0.92	0.20	7.22	1.13
	30–60	13	0.030	0.004	116	24	6.1	1.4	0.46	0.12	6.67	1.18
	60–90	11	0.021	0.002	25	6	5.2	1.0	0.37	0.07	5.21	1.06
Between trees	0–30	10	0.022	0.003	91	21	3.5	0.3	0.31	0.03	6.74	0.75
	30–60	10	0.016	0.001	39	13	3.4	0.3	0.30	0.07	7.30	1.16
	60–90	7	0.017	0.002	42	27	3.8	0.3	0.30	0.06	9.43	3.36

Samples collected using 7.5 cm diameter auger from under 5 *Prosopis* and from between *Prosopis*, s.e. is standard error of the mean

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The large N accumulation under *Prosopis* was probably derived from symbiotic N_2-fixation (Virginia et al. 1981; Rundel et al. 1982) because inputs from other sources appear too small to account for this build-up. *Prosopis* root nodules have been recovered at this site from young plants growing in moist washes.

The climate at Harper's Well is hot and dry. The mean annual temperature is approximately 22° C and daily maximum temperatures during July, the hottest month, are 47° C. Precipitation is sporadic and most of the 70 mm yr^{-1} rainfall occurs from August to March. However, intensive storms from the Gulf of California can drop over 100 mm in a single event. Consequently, anaerobic conditions necessary for denitrification may persist long enough for significant amounts of soil N to be lost to the atmosphere.

In the past, estimates of denitrification have been based on N budget deficits (Allison 1955) or from measuring ^{15}N labeled N_2 or N_2O evolution from soil after additions of ^{15}N enriched fertilizers (Rolston et al. 1976). These methods, however, are poorly suited to non-agricultural soils or sites where N additions may disturb the system in question. Recently a method has been developed allowing direct in-field measurements of denitrification by measuring N_2O evolution from soil treated with acetylene (Ryden et al. 1979). Acetylene inhibits the reduction of N_2O to N_2 during denitrification (Yoshinari and Knowles 1976). Unlike N_2, small fluxes of N_2O from soil can be easily measured by trapping the evolved N_2O on Molecular Sieve 5A with subsequent laboratory analysis by gas chromatography. After wetting soil under *Prosopis* and from the unvegetated soil between *Prosopis* plants, we directly measured denitrification to assess its significance to the overall N cycle of this desert ecosystem.

Methods

Denitrification trials were run in August 1980 and January 1981 after applying 50 mm of distilled water to 1 m^2 areas of soil within the canopy of a mature *Prosopis* and about 4 m from the edge of the canopy. Four N_2O collection boxes ($50 \times 10 \times 17$ cm) were driven 10 cm into the soil in each wetted area. Two ambient air collectors allowed subtraction of background N_2O. Equipment set-up, acetylene flow rate, N_2O collection and analytical procedures were identical to those of Ryden et al. (1979). N_2O was collected for 3 h out of every 4 over a 48 h period.

Results and Discussion

Measurable denitrification occurred after a limited collection period in August, prompting more intensive sample collection in January (Fig. 1). In January, appreciable denitrification occurred under *Prosopis* but denitrification was barely detectable from soil outside the canopy. Denitrification rates under *Prosopis* peaked about 24 h after wetting and were still considerably above background 50 h after wetting. The mean denitrification rate under *Prosopis* was 11.6 g N $ha^{-1}h^{-1}$ compared to 0.2 g N $ha^{-1}h^{-1}$ outside the *Prosopis* canopy. The peak denitrification rate under *Prosopis* was about the same as mean daily rates for fertilized irrigated vegetable crops in S. California measured using the same technique (Ryden and Lund 1980). N_2O evolution above background was already evident 6 h after wetting soil under *Prosopis* indicating a rapid microbial response to anaerobic conditions. Considering the high salinity and extreme dryness of these surface layers prior to wetting, this rapid response is surprising.

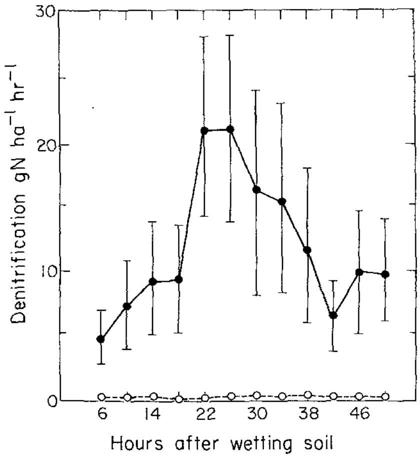

Fig. 1. Denitrification under *Prosopis glandulosa* (*solid line*) and from the unvegetated area between *P. glandulosa* (*dashed line*) at Harper's Well, January 1980. Values are means of 4 N_2O collection boxes. Error bars give ± 1 standard error

Under *Prosopis* there was significant variation between boxes in the magnitude of N flux but the temporal pattern of denitrification was the same for all boxes. The box positioned in the lowest sector of the wetted area under *Prosopis* had a mean denitrification rate of 26.4 g N $ha^{-1}h^{-1}$ compared to the most elevated and probably driest box which had a mean denitrification rate of only 3.0 g N $ha^{-1}h^{-1}$.

Denitrification is clearly associated with the presence of *Prosopis* in this system. The NO_3-N concentration of soil from under and between *Prosopis* is not limiting for denitrification. Other soil conditions then must account for the much higher denitrification rate of the *Prosopis* soil. The dramatic difference in the denitrification rates measured under and between *Prosopis* can best be related to the much higher organic carbon content of the *Prosopis* surface soil compared to the unvegetated soil between *Prosopis* (Table 1). The organic carbon accumulated under *Prosopis* should provide larger quantities of energy yielding organic substrates for denitrifying bacteria than found in the non-*Prosopis* soil. Denitrification is probably energy limited in many desert soils. In laboratory studies anaerobically incubated desert soils have much higher denitrification rates when glucose is added as an energy source (Macgregor 1972; Westerman and Tucker 1978). The slightly lower salinity of the *Prosopis* surface soil along with possible rhizosphere stimulation of denitrifying bacteria (Smith and Tiedje 1979) may also contribute to the greater N loss under *Prosopis*.

On an ecosystem basis, N losses through denitrification are probably not significant considering the large amounts of NO_3-N found in the surface soil. After rare major rainfalls about 0.5 kg N ha^{-1} of *Prosopis* cover could be lost via denitrification. On an ecosystem basis N loss would be considerably smaller since *Prosopis* cover at Harper's Well is only 30%. Low long-term rates of denitrification must be an important factor allowing the accumulation of large quantities of NO_3-N in this ecosystem. In desert soils with much lower N contents, denitrification may make a greater relative impact on the overall N cycle.

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